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Neutrosophic Statistical Analysis of the Efficacy of Biostimulants in Amaranth Varieties

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Abstract. This study evaluated the effects of biostimulants on two varieties of amaranth, Valentina (Amaranthus tricolor) and Nezhenka (Amaranthus hybridus), in terms of germination, growth, and biomass production. Using neutrosophic statistics allowed for the measurement of indeterminacies and the analysis of variables such as days to germination, stem length, number of leaves, and biomass production. The results showed that seaweed extract was the most effective biostimulant, accelerating germination, increasing stem length and the number of leaves, and maximizing biomass production. Meanwhile, Nezhenka stood out for its superior biomass production, especially with seaweed extract, while Valentina was notable for its rapid germination. These findings suggest that the selection of biostimulants and varieties should be strategic to optimize agricultural yield.

Keywords: Germination, seaweed extract, cultivation, neutrosophic Statistics

1 Introduction

The genus Amaranthus includes between 60 and 90 species, with approximately 55 of them distributed globally. Specifically, Russia hosts about 16 species in the wild. In Ecuador, the Alegría variety is cultivated by the National Institute of Agricultural Research (INIAP). Historical and genetic studies have demonstrated that the origin of Amaranthus is in America [1], with A. cruentus, A. caudatus, and A. hipochondriacus as the main species domesticated for grain [2]. Another notable point about Amaranthus is that they descend from the wild species A. powelli, A. quitensis, and A. hybridus respectively. It is suggested that A. quitensis might be synonymous with A. hybridus, which would be the ancestor of these cultivated species.

The species suitable for foliage production include A. dubius, A. blitum, A. hybridus, A. quitensis, and A. tricolor [3]. In terms of selection and hybridization, modern varieties of amaranth include A. cruentus, A. caudatus, A. hipochondriacus, A. mantegazzianus, and A. paniculatus for seed production, while A. tricolor, A. caudatus, A. spinosus, and A. cruentus are used both in horticulture and in decorative and medicinal applications [4].

Historically, amaranth has been a fundamental crop in America for over 4000 years, promoted by the Mayas in Mexico and Guatemala and the Incas in Ecuador, Peru, and Bolivia. White seed varieties were preferred over dark ones, aiding their domestication. Currently, grain amaranth production is most notable in the inter-Andean valleys of Peru, Bolivia, and northern Argentina, although it is marginal in the Colombian and Ecuadorian highlands.

In India, China, and some African countries, amaranth is mainly cultivated for biomass production as a vegetable. Nutritionally [5], 150-200 grams of amaranth leaves are equivalent to 1 kg of tomatoes or cucumbers, and 100 grams of leaves contain 13.1 g of dry matter, 3.5 g of protein, 0.5 g of fat, 256 mg of calcium, 67 mg of phosphorus, 3.9 mg of iron, 411 mg of sodium, and 80 mg of vitamin C [6]. Additionally, 18 sterols have been identified in the leaves of amaranth [7], some with medical applications for treating atherosclerosis [8].

The use of biostimulants in this study is motivated by the high dependence on agrochemicals in Ecuador, where between 60% and 70% of cultivated lands are treated with these products. A biostimulant is a substance or microorganism that enhances the efficiency of plants in nutrient absorption and assimilation, increases stress tolerance, and improves agronomic characteristics, irrespective of its nutritional content.

This study underscores the agronomic and nutritional relevance of amaranth, as well as the need to optimize its production through the conscious use of biostimulants to reduce dependence on agrochemicals. Therefore, the research aims to evaluate the effect of different biostimulators on the growth and development of the amaranth varieties Valentina and Nezhenka, to determine which of these products offers the greatest improvement in terms of days to germination, stem length, number of leaves, and biomass production. For the modeling and development of the study, the use of neutrosophic statistics is necessary to include, analyze, and assess the existing indeterminacies.

2 Materials and Methods

2.1 Neutrosophic Statistics

Neutrosophic probabilities and statistics are an extension of classical methods that incorporate a third component of indeterminacy [9], allowing for the analysis of events with imprecise, incomplete, or unknown information. This approach utilizes neutrosophic numbers and neutrosophic random variables to describe uncertainty [10] and is based on the definition of neutrosophic probabilities that sum up to a maximum of three, instead of one [11]. Neutrosophic descriptive statistics, such as neutrosophic mean, variance, and coefficient of variation, are used to summarize and analyze data with indeterminate or complex characteristics (according to the methodology in referenced studies [12] [13] [14] [15]).

Neutrosophic inferential statistics involve techniques that enable the extension of neutrosophic sampling to a population that the sample was taken from.

Neutrosophic data are data that possess a degree of indeterminacy. Similar to classical statistics, it can be categorized as:

- Discrete neutrosophic data refers to values that are individual points, such as 7+i_1, where i_1 is a number between 0 and 1, 2, 38+i_2, where i_2 is a number between 10 and 12. - Continuous neutrosophic data refers to values that form one or more intervals, such as [0.05, 0.1] or [0.9, 1.0] (meaning it is uncertain which specific value within the interval is being referred to).

Additional categorization:

- Neutrosophic data can be classified into two types: quantitative (numerical) and qualitative (categorical). - Quantitative neutrosophic data refers to numerical values that are uncertain, such as a number within the range of 3 to 8, or a set of numbers like 50, 53, 58, or 61, where the exact value is unknown.

- Qualitative neutrosophic data refers to categorical values that are uncertain, such as colors like blue or red, or a set of colors like white, black, green, or yellow, where the exact color is unknown.

In addition, we can categorize the data into two types: neutrosophic data univariate, which refers to data that consists of observations on a single neutrosophic attribute, and multivariate neutrosophic data, which refers to data that consists of observations on two or more attributes. Specifically, we refer to the bivariate neutrosophic data and the trivariate neutrosophic data in certain instances [16, 17].

3 Results

3.1 Study Environment

In the study conducted in Cunchibamba, Tungurahua, a 2x4 factorial experimental design with four replications and a total of 32 experimental units was used to evaluate the effect of different biostimulants on two varieties of amaranth, A. tricolor (Valentina) and A. hybridus (Nezhenka). Each experimental unit measured 3m x 1m, totaling 3 m², with 20 plants per unit and 10 plants per evaluated plot. The evaluated factors included:

- Factor A: Amaranthus Varieties
- V1: Valentina (A. tricolor)
- V2: Nezhenka (A. hybridus)
- Factor B: Growth Biostimulants (see Table 1)

For each variety, agronomic parameters such as days to emergence, stem length, number of leaves per plant, and biomass production were measured. Stem length was measured every 15 days from the base of the stem to the beginning of the inflorescence, using a tape measure. Additionally, the number of leaves was assessed every 30 days from the base of the stem to the base of the panicle throughout the vegetative cycle.

Table 1: Description of biostimulant factors.

Code	Biostimulant	Description	Main application
B0	Without biostimulant	Control, no application of additional biostimulants.	Used to establish a baseline in the research, by comparing the effects of other treatments.
B1	seaweed extract	Contains micronutrients, vitamins, and natural hormones that promote growth and health.	Enhances germination and vegetative growth, and increases resistance to abiotic stress.

Code	Biostimulant	Description	Main application
B2	basfoliar algae	Prepared from seaweed, rich in essential nutrients such as potassium, iron, and zinc.	Stimulates root and leaf growth, improves nutrient absorption and enhances biomass quality.
B3	Active basfoliar	Combination of microelements and growth promoters designed for rapid absorption.	Suitable for critical stages of development, increases biomass production, and improves photosynthetic efficiency.

Yield in kg/ha was determined by collecting leaf samples from 1m² per experimental unit. Fresh samples were weighed and then dried on aluminum trays and manila envelopes inside an incubator. The drying process began at 30°C for 48 hours, increasing to 60°C for an additional 24 hours, after which the dry weight was recorded in grams and converted to kg/ha.

Each of these biostimulants offers different advantages and mechanisms of action, which are explored in the study to determine their impact on the growth and development of the amaranth varieties Nezhenka and Valentina. Therefore, it allows researchers and agricultural practitioners to better understand how each type of biostimulant should be used to optimize cultivation practices and achieve desirable agronomic results.

3.2 Germination parameter

Once the study environment has been analyzed, the neutrosophic ranges of the germination variable are defined. Subsequently, the Valentina and Nezhenka samples are evaluated and analyzed against this parameter, reflecting the previous results and observations. Below, the ranges and germination results of the Amaranths species are presented (see Tables 2 and 3).

Table 2: Neutrosophic ranges for the germination variable.

Code	Neutrosophic expression	Neutrosophic number	Variable range	Description
G1	Very fast	(0.95, 0.05, 0.00)	≤ 4 days	Germination in less than 5 days
G2	Fast	(0.75, 0.20, 0.05)	5-7 days	fast germination
G3	Moderate	(0.50, 0.30, 0.20)	8-10 days	Moderate germination
G4	Slow	(0.25, 0.50, 0.25)	11-14 days	slow germination
G5	Very slow	(0.05, 0.70, 0.25)	≥ 15 days	Very slow germination

Table 3: Germination results of Amaranths species.

Variety	Days until germination	Neutrosophic evaluation	Triple neutrosophic number	Description
Valentina	4	G1 (Very Fast)	(0.95, 0.05, 0.00)	Germination < 5 days
Valentina	6	G2 (Fast)	(0.75, 0.20, 0.05)	Germination 5-7 days
Nezhenka	9	G3 (Moderate)	(0.50, 0.30, 0.20)	Germination 8-10 days
Nezhenka	12	G4 (Slow)	(0.25, 0.50, 0.25)	Germination 11-14 days

Neutrosophic statistical analysis:

I. Valentina:
- It exhibits "Very Fast" germination in just 4 days, aligning with the G1 range. This reflects its adaptability and efficiency under optimal conditions, with early seedling emergence.
- After 6 days, its germination is classified as "Rapid" (G2), indicating that even slightly outside the ideal conditions, Valentina maintains a good emergence rate.

II. Nezhenka:
- At 9 days, it falls into the "Moderate" range (G3), showing slower germination compared to Valentina, but still within an acceptable framework for healthy development.
- For 12 days, its germination is described as "Slow" (G4), which underlines its longer cycle nature and slower adaptation compared to Valentina.

Based on the neutrosophic data and the description of the previous results, it underscores how Valentina and Nezhenka respond to germination conditions. Valentina demonstrates greater speed and effectiveness in seedling emergence, while Nezhenka shows a more gradual process. This reflects the importance of selecting the right variety according to the specific conditions and goals of the crop.

3.3 Stem Length Parameter

Secondly, the neutrosophic ranges of the stem length variable are defined, to evaluate and analyze the samples of Valentina and Nezhenka and their development in relation to this parameter. Below, the ranges and the results of stem length in the Amaranths varieties Valentina and Nezhenka are presented (see Tables 4 and 5).

Table 4: Neutrosophic ranges for variable stem length.

Code	Neutrosophic expression	Neutrosophic number	Variable range	Description
L1	Very Low	(0.10, 0.85, 0.05)	0-10cm	Insufficient growth
L2	Low	(0.30, 0.60, 0.10)	10-20cm	Low but improvable growth
L3	Moderate	(0.50, 0.45, 0.05)	20-30cm	Moderate growth
L4	High	(0.75, 0.20, 0.05)	30-40cm	Good growth almost ideal
L5	Very high	(0.90, 0.05, 0.05)	>40cm	Ideal excellent growth

Table 5: Results of variable stem length in Amaranths varieties.

Variety	Stem length (cm)	Neutrosophic evaluation	triple neutrosophic number	Description
Valentina	eleven	L2 (Low)	(0.30, 0.60, 0.10)	Low growth
Valentina	18	L3 (Moderate)	(0.50, 0.45, 0.05)	Moderate growth
Nezhenka	44	L5 (Very High)	(0.90, 0.05, 0.05)	Excellent growth
Nezhenka	30	L4 (High)	(0.75, 0.20, 0.05)	good growth

Neutrosophic statistical analysis:

I. Valentina:
- At 11 cm, Valentina falls into the "Low" range (L2), indicating insufficient growth, but with potential for improvement.
- At 18 cm, the plant shows "Moderate Growth" (L3), reflecting a substantial improvement under more favorable conditions, especially with the use of algae extract.

II. Nezhenka:
- At 44 cm, Nezhenka shows "Excellent Growth" (L5), indicating optimal adaptation and maximum use of resources under the seaweed extract treatment.
- At 30 cm, it is classified as "High" (L4), showing robust and productive growth, suitable for biomass production.

The neutrosophic data illustrate how Valentina and Nezhenka respond in terms of stem length under different treatments. While Valentina shows moderate growth, Nezhenka excels with very high growth, especially under the use of seaweed extract. These results underline the importance of selecting the right variety and treatment to optimize stem growth and the overall productivity of the plants. This neutrosophic approach provides a rich and detailed perspective for understanding and improving agronomic strategies based on the specific characteristics and responses of each amaranth variety.

Analysis of stem length for combinations of varieties with biostimulants: This neutrosophic analysis helps to visualize and quantify how biostimulants differentially affect amaranth varieties. It emphasizes the importance of properly selecting both the variety and the treatment. Additionally, agronomic results must be optimized based on the combination of the selected variety and biostimulant (see Table 6).

Table 6: Behavior of stem length for Amaranths varieties Valentina and Nezhenka under different treatments with biostimulators

Variety + Biostimulator	Stem Length (cm)	Neutrosophic Evaluation	Triple Neutrosophic Number	Description	Variety + Biostimulator
Nezhenka + Seaweed Extract (V2B1)	54.30	L5 (Very High)	(0.90, 0.05, 0.05)	Excellent growth	Nezhenka + Seaweed Extract (V2B1)
Nezhenka + Basfoliar Algae (V2B2)	50.44	L5 (Very High)	(0.90, 0.05, 0.05)	Excellent growth	Nezhenka + Basfoliar Algae (V2B2)
Nezhenka + Without Biostimulator (V2B0)	49.61	L5 (Very High)	(0.90, 0.05, 0.05)	Excellent growth	Nezhenka + Without Biostimulator (V2B0)
Nezhenka + Active Basfoliar (V2B3)	44.97	L5 (Very High)	(0.90, 0.05, 0.05)	Excellent growth	Nezhenka + Active Basfoliar (V2B3)
Valentina + Seaweed Extract (V1B1)	13.53	L2 (Low)	(0.30, 0.60, 0.10)	Low growth	Valentina + Seaweed Extract (V1B1)
Valentina + Basfoliar Algae (V1B2)	12.72	L2 (Low)	(0.30, 0.60, 0.10)	Low growth	Valentina + Basfoliar Algae (V1B2)
Valentina + Without Biostimulator (V1B0)	11.88	L2 (Low)	(0.30, 0.60, 0.10)	Low growth	Valentina + Without Biostimulator (V1B0)

Variety + Biostimulator	Stem Length (cm)	Neutrosophic Evaluation	Triple Neutrosophic Number	Description	Variety + Biostimulator
Valentina + Active Basfoliar (V1B3)	11.36	L2 (Low)	(0.30, 0.60, 0.10)	Low growth	Valentina + Active Basfoliar (V1B3)

Neutrosophic statistical analysis:

I. Nezhenka:
- With Algae Extract (V2B1), Nezhenka achieves "Excellent Growth" with 54.30 cm, showing the maximum efficiency of this biostimulator.
- With Active Basfoliar (V2B3), although the length is the smallest for Nezhenka in these treatments, it is classified as "Excellent Growth" with 44.97 cm, indicating that even the least effective of the treatments evaluated maintains high growth.

II. Valentina:
- With Seaweed Extract (V1B1), Valentina shows low growth (13.53 cm), which is the best result for this variety but is still in a low range.
- With Active Basfoliar (V1B3), stem length is the lowest for Valentina in these treatments at 11.36 cm. So it keeps growth at a low level.

The results of the study clearly show the superiority of Nezhenka in terms of stem length under all treatments, with values consistently in the "Very High" range. In contrast, Valentina shows improvements with the biostimulants but remains in the "Low" range. This indicates a limitation in its ability to utilize these treatments to significantly enhance its vertical growth.

3.4 Number of sheets parameter

Thirdly, the neutrosophic ranges for the variable number of leaves are defined, to evaluate and analyze the samples of Valentina and Nezhenka. Below, the ranges and the results for the number of leaves in the varieties, under different treatments with biostimulants, are presented (see Tables 7 and 8).

Table 7: Neutrosophic ranges for the variable number of leaves.

Code	Neutrosophic expression	Neutrosophic number	Variable range	Description
H1	Very Low	(0.10, 0.85, 0.05)	≤ 5 sheets	Insufficient number of sheets
H2	Low	(0.30, 0.60, 0.10)	6-10 sheets	Few leaves, needs improvement
H3	Moderate	(0.50, 0.45, 0.05)	11-15 sheets	Moderate number of leaves
H4	High	(0.75, 0.20, 0.05)	16-20 sheets	Good number of leaves
H5	Very high	(0.90, 0.05, 0.05)	> 20 sheets	Excellent number of leaves

Table 8: Behavior of the number of leaves for the Amaranths varieties Valentina and Nezhenka under the different treatments with biostimulators.

Variety + Biostimulator	Number of sheets	Neutrosophic Evaluation	Neutrosophic Number	Description
Nezhenka + Seaweed Extract (V2B1)	40.9	H5 (Very High)	(0.90, 0.05, 0.05)	Excellent number of leaves
Nezhenka + Basfoliar Algae (V2B2)	38.98	H5 (Very High)	(0.90, 0.05, 0.05)	Excellent number of leaves
Nezhenka + Without Biostimulator (V2B0)	38.45	H5 (Very High)	(0.90, 0.05, 0.05)	Excellent number of leaves
Nezhenka + Basfoliar active (V2B3)	33.28	H5 (Very High)	(0.90, 0.05, 0.05)	Excellent number of leaves
Valentina + Seaweed Extract (V1B1)	15.93	H3 (Moderate)	(0.50, 0.45, 0.05)	Moderate number of leaves
Valentina + Basfoliar Algae (V1B2)	14.68	H3 (Moderate)	(0.50, 0.45, 0.05)	Moderate number of leaves
Valentina + Without Biostimulator (V1B0)	12.83	H3 (Moderate)	(0.50, 0.45, 0.05)	Moderate number of leaves
Valentina + Basfoliar active (V1B3)	12.53	H3 (Moderate)	(0.50, 0.45, 0.05)	Moderate number of leaves

Neutrosophic statistical analysis:

I. Nezhenka:
   - It exhibits an "Excellent number of leaves" in all treatments, greatly exceeding the threshold of 20 leaves, reflecting the ability to produce a large amount of foliage under various treatment conditions.

II. Valentina:
   - It shows a "Moderate number of leaves" in all treatments with biostimulators, ranging between 11 and 15 leaves. Although it does not reach the levels of Nezhenka, it maintains consistent leaf growth that reflects its adaptive capacity under different treatments.

From the analyzed data, it is determined that Valentina and Nezhenka respond in terms of leaf production under different treatments with biostimulants. While Nezhenka demonstrates a superior ability to generate an exceptional number of leaves, Valentina exhibits moderate performance, indicating significant differences in the biological response between the two varieties.

3.5 Biomass Performance Parameter

Lastly, the biomass yield parameter (Kg/ha) is analyzed, using the following neutrosophic ranges of the variable defined in table 9. Additionally, the results and observations of biomass yield in amaranth crops are analyzed (see Table 10).

Table 9: Neutrosophic ranges for the biomass yield variable.

Code	Neutrosophic expression	Neutrosophic number	Variable range	Description
B1	Very Low	(0.05, 0.90, 0.05)	≤ 50 kg/ha	Insufficient biomass production
B2	Low	(0.25, 0.70, 0.05)	51-100 kg/ha	Low production, requires improvements
B3	Moderate	(0.50, 0.45, 0.05)	101-150 kg/ha	Moderate production
B4	High	(0.75, 0.20, 0.05)	151-200 kg/ha	Good production, almost ideal
B5	Very high	(0.95, 0.05, 0.00)	>200 kg/ha	Exceptionally high biomass production

Table 10: Behavior of biomass yield under different treatments with biostimulators.

Biostimulator	Biomass Yield (kg/ha)	Neutrosophic Evaluation	Triple Neutrosophic Number	Description
Seaweed Extract (B1)	133.94	B3 (Moderate)	(0.50, 0.45, 0.05)	Moderate production
Basfoliar Algae (B2)	131.8	B3 (Moderate)	(0.50, 0.45, 0.05)	Moderate production
Without Biostimulator (B0)	107.43	B2 (Low)	(0.25, 0.70, 0.05)	Low production
Basfoliar Aktiv (B3)	106.74	B2 (Low)	(0.25, 0.70, 0.05)	Low production

Neutrosophic statistical analysis:

- ❖ Seaweed Extract and Basfoliar Seaweed show moderate yields, ranging from 101-150 kg/ha. This underlines their effectiveness as biostimulators that promote considerable biomass production.
- ❖ Without Biostimulator and Basfoliar Aktiv, on the other hand, present lower yields, in the range of 51-100 kg/ha, indicating lower effectiveness in promoting biomass growth.

The results reflect how different biostimulators affect biomass yield in amaranth crops. The Seaweed Extract and Basfoliar Seaweed show a moderate yield, which makes them more effective compared to treatments without a biostimulator or with Basfoliar Aktiv, as they present lower yields.

3.6 Comprehensive evaluation of amaranth varieties and applied biostimulators.

Neutrosophic Comparative Analysis: The following table provides a detailed and nuanced representation of the behavior of variables under different conditions. This is crucial for decision-making in agronomic management and the optimization of treatments in amaranth crops (see Table 11). For this purpose, neutrosophic categories for the mean, variance, and standard deviation are provided. These are assigned based on the interpretation of the neutrosophic results obtained, which better describe the variability and behavior of each variable under different treatments. These descriptions offer a richer and more contextualized perspective of the data, which is particularly useful in agricultural research where biological variability and indetermination are significant.

Table 11: Neutrosophic statistics of the variety and applied biostimulator. S

Variety + biostimulator	Variable	Neutrosophic mean	Neutrosophic variance	Neutrosophic standard deviation
Nezhenka + seaweed extract	Stem length	Very high	Moderate	Moderate
	Number of sheets	Very high	High	High
	Biomass yield	High	Moderate	Moderate
	Germination	Very fast	Low	Low
Nezhenka + basfoliar algae	stem length	High	Moderate	Moderate
	Number of sheets	Very high	High	High
	Biomass yield	High	Moderate	Moderate
	Germination	Fast	Low	Low
Nezhenka + without biostimulator	stem length	High	Moderate	Moderate
	Number of sheets	High	High	High
	Biomass yield	Moderate	Low	Low
	Germination	Moderate	Moderate	Moderate
Nezhenka + basfoliar Aktiv	stem length	Moderate	High	High
	Number of sheets	High	Very high	Very high
	Biomass yield	Moderate	Low	Low
	Germination	Slow	Moderate	Moderate
Valentina + seaweed extract	stem length	Low	Very low	Very low
	Number of sheets	Moderate	Moderate	Moderate
	Biomass yield	Low	Very low	Very low
	Germination	Moderate	High	High
Valentina + basfoliar algae	stem length	Very low	Very low	Very low
	Number of sheets	Moderate	Moderate	Moderate
	Biomass yield	Low	Very low	Very low
	Germination	Slow	High	High

Neutrosophic Statistical and Comparative Analysis on Amaranth Varieties and Biostimulants: Neutrosophic analysis offers a comprehensive approach to interpreting data where uncertainty and incomplete information play a crucial role. This allows for a deeper and more nuanced understanding than traditional statistical methods. The following integrated results are presented:

- ❖ Germination: Valentina showed superior germination (T: 0.85, I: 0.10, F: 0.05) compared to Nezhenka (T: 0.62, I: 0.20, F: 0.18), indicating rapid adaptability and robustness under controlled conditions. This is interpreted as Valentina's intrinsic ability to quickly adapt to new environments, which is essential in selecting crops for areas with climatic variability.
- ❖ Stem Length: Nezhenka exhibited significantly greater stem growth (T: 0.85, I: 0.10, F: 0.05) compared to Valentina, especially when seaweed extract was used. This indicates that Nezhenka responds well to certain biostimulants, showing significant agronomic potential in terms of vertical growth, which can be beneficial to maximize space use in controlled environments.
- ❖ Number of Leaves: Nezhenka also displayed a higher number of leaves under treatment with seaweed extract (T: 0.90, I: 0.05, F: 0.05), highlighting the ability to produce more foliar biomass, a desirable characteristic for forage production or leaf consumption.
- ❖ Biomass Yield: In terms of biomass, Nezhenka significantly outperformed Valentina with the use of seaweed extract, indicating that Nezhenka not only grows taller but also produces more total biomass. Thus, this variety constitutes a superior candidate for biomass production.
- ❖ This neutrosophic analysis reinforces the importance of selecting specific varieties and treatments according to their response to biostimulants and optimizing cultivation strategies to achieve the best possible agricultural outcomes.

4 Discussion

The results, along with previous studies conducted in both Ecuador and Russia, show consistency in Nezhenka's response to biostimulants. This suggests that Nezhenka's genetic characteristics may be well adapted to the use of biostimulants to optimize its growth. Meanwhile, although Valentina showed lower performance in several parameters, it presents more efficient germination, which is crucial for the initial crop establishment stage. However, the data also suggest that Valentina may be more sensitive to transplant conditions, a variable that must be carefully managed to maximize its potential. Lastly, the use of neutrosophic statistics not only allows for a richer and more complex evaluation of experimental data but also helps design more informed and adaptive agronomic strategies that take into account the variability and uncertainty of agricultural production.

5 Conclusion

The neutrosophic statistical analysis revealed that Nezhenka has demonstrated a notably positive response to the use of seaweed extract. This resulted in a significant increase in stem length and biomass production. This response suggests that Nezhenka could be especially beneficial in cultivation programs that incorporate biostimulants to enhance growth efficiency and productivity.

Valentina displayed a superior germination rate, particularly under controlled conditions, reflecting its ability to adapt quickly and establish itself effectively at the start of the crop cycle. This characteristic is critical for agricultural planning and can be a decisive factor in selecting varieties for areas with short growing seasons or unstable climate conditions.

The study highlighted Valentina's sensitivity to transplant conditions, which could adversely affect its development and yield. This underscores the importance of careful and well-planned agronomic management practices to ensure that all amaranth varieties reach their maximum potential. Thus, it emphasizes the need for strategies tailored to the specific characteristics of each variety.

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